DUPLICATE

METEOROLOGICAL OFFICE

Forecasting Research

Forecasting Research Division
Technical Report No. 141

Results of merging automated nowcasts and mesoscale model forecasts of precipitation

by

N. Thomas, B.J. Conway and B.W. Golding

20 December 1994

Meteorological Office
London Road
Bracknell
Berkshire
RG12 2SZ
United Kingdom

ORGS UKMO F
National Meteorological Library
FitzRoy Road, Exeter, Devon. EX1 3PB

Forecasting Research Division
Technical Report No. 141

Results of merging automated nowcasts and mesoscale model forecasts of precipitation

N. Thomas, B.J. Conway and B.W. Golding

20 December 1994

© Crown Copyright 1994

Forecasting Research
Meteorological Office
London Road
Bracknell
RG12 2SZ

Contents

1 Introduction 1

2 Calculation of the merged forecasts 1

2.1 Precipitation rate forecasts 1

2.2 Accumulation forecasts 2

3 Assessment of the merged forecasts 3

3.1 The test-cases used 3

3.2 Precipitation rate forecasts 3

3.3 Accumulation forecasts 5

4 Results 6

4.1 Precipitation rate forecasts 6

4.2 Accumulation forecasts 7

4.3 Subjective assessments 8

5 Conclusions 9

6 Recommendations 9

7 References 10

Appendix: summary of the nine cases used 11

Figures 15

1 Introduction

Nimrod will produce analyses and 0-6h forecasts for the UK and surrounding waters of a range of weather parameters, including instantaneous and accumulated precipitation. Until now the available precipitation forecasts have been of two sorts: nowcasts, derived from radar and satellite observations by extrapolation or advection, and forecasts from the mesoscale version of the Unified Model (referred to hereafter as 'NMM', for New Mesoscale Model).

These two types of forecast, though the subject of much development, have remained entirely separate. This paper outlines recent work to merge the forecasts from the two sources, and presents assessments of the resultant combined forecasts in a variety of cases.

The merged forecast attempts to combine the detail and accuracy of the nowcasts in the first part of the forecast period with the NMM's ability to predict development and decay of precipitation in the latter part of the period, when the accuracy of the nowcasts usually falls below that of the NMM products.

2 Calculation of the merged forecasts

2.1 Precipitation rate forecasts

Golding (1994) proposed a scheme for merging nowcasts and NMM forecasts of precipitation rate for Nimrod. The scheme has been implemented with only minor modifications, and the final version, used to produce the results assessed later in the paper, is outlined below.

The controlling program for merging the two rainfall forecasts begins by pre-processing the data presented to it and then calls a sequence of subroutines for the various stages of the merging process. Orographic correction fields (Thomas, 1993) and precipitation nowcasts (including the base image (T+0) from which they were created) are read in. Orographic enhancements are removed from the base image (but not from the nowcasts, which are produced in an already disenhanced state). The NMM precipitation fields are then read in and orographically disenhanced. This is done by averaging the pixel corrections around each grid point and then subtracting these grid-scale corrections from the model data before they are interpolated into image pixels.

Merging the two forecast sequences involves eight steps, each a subroutine within the main program. The first three steps are only performed once but the remaining five steps are repeated for each of the six forecast hours. The steps are :

i) calculating the relative weights of the two types of forecast at each of the six forecast hours - this is based on a fixed exponential decrease in the accuracy of the nowcasts and a constant model accuracy which is fixed at a value dependent on the performance

of the model's precipitation forecast at the base time, as assessed by program `object_motion` (Conway *et al*, 1993);

ii) calculating the probability of precipitation at each pixel in the model forecasts for each precipitation rate - the probability is set to either zero if the forecast precipitation rate at a point is less than the current rate being considered, or one if the rate is greater than or equal to the rate being considered ; 1/10 of the probability of the next lower rate at that point is then added to the probability for the current rate, for the lowest rate 1/10 of the cloud fraction is used;

iii) predicting the populations of each precipitation rate at each forecast time - this is done by counting the number of pixels of each rate in the base image (analysed field) and the "probabilities" in the model prediction for that same time (T+0), and then adjusting the counts of model pixels for the forecast times (T+1 to T+6) by the ratio of analysed to model pixels found at T+0;

iv) calculating the probability of precipitation at each pixel in the nowcasts for each precipitation rate - the probabilities are simply set to either 1 or 0 depending on whether or not the pixel contains precipitation at or above that rate. These probability fields are then smoothed;

v) smoothing the model forecast probabilities in the same way as the nowcast probabilities are smoothed in step iv) above;

vi) forming a weighted average of the two sets of probabilities to yield a single set of probability fields;

vii) calculating the threshold probabilities which give the forecast populations at each precipitation rate;

viii) adding model precipitation which has been interpolated using a fractal algorithm to the areas previously defined as "no data" in the merged forecasts - the areas of no data arising from the physical limit to the extent of the radar network.

The merged forecast field is then orographically enhanced and written to disk. The program repeats steps iv) to viii) for the next forecast time, or terminates if all forecast times have been dealt with.

2.2 Accumulation forecasts

A different method is used to calculate the merged accumulation forecasts, as the method described at §2.1 above is not directly applicable.

Accumulation nowcasts are first produced as outlined by Thomas *et al* (1993), by summing

the precipitation deposited as radar rainfall pixels are moved in small steps. Each pixel uses its own timestep, dependent on its velocity, the value being a compromise between computing cost and accumulation error.

The program generates a series of twenty-four 15-minute accumulation nowcasts. For the purposes of these tests, 60-minute accumulation forecasts were formed by summing sequences of four 15-minute fields.

The merged accumulation forecast fields used in these tests are each a linear combination of a 60-minute accumulation nowcast and a 60-minute NMM accumulation forecast. The NMM product is the sum of four components: grid-scale and convective rain, and grid-scale and convective snow.

The weighting factors used in combining the nowcasts and NMM forecasts are the same as those used for the merged precipitation rate forecasts (a case-invariant exponentially decaying weight for the extrapolation forecast and a case-dependent but time-invariant NMM weight derived from the quality of the NMM rate forecast at the base-image time). NMM weights are not allowed to be lower than 0.001, a restriction that prevents the scheme producing negative accumulations if negative model weights are encountered.

Outside the region of the radar-based extrapolation forecast (limited by the range of the radar observations) the NMM accumulation forecasts are used alone. Fractal interpolations of the NMM product are not used, as accumulation fields tend to be more smeared than instantaneous precipitation rates so the raw model products are less unrealistic in their case.

A forecast based on a simple linear combination is quick to compute, but means that precipitation will occur in the merged forecast wherever it occurs in *either* of the two constituent forecasts (unless the merged value falls below 1/64 mm - half the value of the smallest allowed non-zero accumulation). This results in over-prediction of the extent of accumulated precipitation. To overcome this, the union is formed of the spatial distributions of the merged precipitation (rate) forecasts at the start and end of each accumulation hour; this is then used as a mask, outside which the accumulation forecast is set to zero.

3 Assessment of the merged forecasts

3.1 The test-cases used

Nine test-cases were selected, encompassing a variety of situations and forecasting problems. They are listed in Table 1 and described in the Appendix.

3.2 Precipitation rate forecasts

The nowcasts, NMM forecasts and merged precipitation rate forecasts were assessed by

comparing them with MRADCMs (FRONTIERS quality controlled radar composite actuals). Evaluation took place within the 'shallow layer usable data boundary' of the MRADCMs - the region of most reliable radar coverage.

Date	Base Time	Description
21nov93	10:00	Showers with a land breeze
25nov93	12:00	Slowing and decaying front
7dec93	04:00	Front with small wave and showers
11feb94	04:00	Front appears to change direction
24feb94	04:00	Messy decay
27feb94	14:00	Rotating fronts with decay
09apr94	08:00	Rotating arctic front and showers
19apr94	07:00	Rotating fronts and showers
24jun94	13:00	Mesoscale Convective System (M.C.S.)

Table 1: Test-cases used

3.2.1 Location assessment

The rainfall maps (forecast and observed) were first converted to rain/no-rain maps using a threshold value of 0.125 mmh^{-1}. They were then passed through a 50 km (25 km half width at half height) Gaussian filter (Thomas *et al*, 1993) before being compared, in accordance with the Nimrod User Requirement (U-R).

Forecasts were evaluated within the region defined by the 'shallow layer usable data boundaries' (UDB) of the MRADCMs.

The filtered forecasts and actuals were compared at each 5 km pixel within the UDB. 2×2 contingency tables prepared containing elements A, B, C, D, where A = number of pixels with rain forecast and observed, B = number observed but not forecast, C = number forecast but not observed, and D = number where rain was neither forecast nor observed. Tables were formed for each type of forecast (nowcast, NMM and merged) for each case, and aggregate values of A, B, C and D were calculated for each forecast type.

The False Alarm Rate (FAR = C/(A+C)) and Hit Rate (HR = A/(A+B)) were calculated for each forecast time in each case study for each forecast type. Weighted average values of FAR and HR over all the cases at each time and for each forecast type were formed from the

aggregate values of A, B and C.

3.2.2 Intensity assessment

Objective intensity assessment of the merged precipitation rate forecasts was in terms of RMSF, as defined in the Nimrod U-R.

Comparison was with the MRADCM at the forecast VT. Forecasts were again evaluated within the region defined by the shallow layer UDBs of the MRADCMs. The images were *not* filtered before comparison.

RMSF was based on 3×3 pixel (15 km square) samples. The mean precipitation rate of the nine pixels in the sample was the value used. The X or Y displacement between successive samples was 1 pixel and only those samples with all nine pixels within the evaluation region were accepted. Of these, only those in which both the forecast and actual rates were at least 0.125 mmh^{-1} were classed as 'valid samples' and allowed to contribute to the RMSF.

RMSF values were calculated for each case, time and forecast type. Mean values (weighted by the number of valid samples) were calculated for each forecast type at T+1, T+3 and T+6.

3.3 Accumulation forecasts

Objective assessment of the merged accumulation forecasts was in terms of RMSF only.

The 60-minute accumulation forecasts were compared with 'actuals' formed from weighted sums of FRONTIERS corrected radar composites (MRADCMs) at 15-minute intervals. Five such MRADCMs would normally be used for each actual, those at 00 and 60 minutes having a weight of ⅛, those at 15, 30 and 45 minutes a weight of ¼.

Forecasts were again evaluated within the region defined by the shallow layer UDB of the MRADCMs. This region sometimes varied during the hour because of the temporary absence of individual radars. The region used for evaluation was the *intersection* of the individual usable areas, i.e., only those pixels present within the UDB throughout the hour.

RMSF was calculated exactly as for the precipitation rate forecasts (§3.2.2), except that the threshold value for valid samples was 0.2 mm.

RMSF values were calculated for each case, time and forecast type. Mean values (weighted by the number of valid samples) were calculated for each forecast type at T+1, T+3 and T+6.

4 Results

4.1 Precipitation rate forecasts

4.1.1 Location

Mean FAR and HR scores at T+1, T+3 and T+6 for the nine cases are presented in Table 2.

	FAR < 30% @ T+1	FAR < 50% @ T+3	FAR < 60% @ T+6	HR > 70% @ T+1	HR > 60% @ T+3	HR > 50% @ T+6
Nowcast	22.82	48.06	67.02	70.41	44.04	28.15
NMM	65.32	67.51	71.96	60.92	61.40	56.29
Merged	20.68	50.74	67.87	74.05	54.15	48.20

Table 2. Weighted mean FAR and HR given as percentages.
Column headers show Nimrod U-R targets.

The Nimrod U-R's mandatory target was attained for both FAR and HR at T+1 only, but was only narrowly missed at T+3 in terms of FAR and at T+6 in terms of HR.

At T+1 the merged FAR and HR were better than those of either of the two component forecasts. HR(merged) at T+3 was intermediate between the nowcast and NMM scores; at other times the merged product approached the performance of whichever was the better of the two component forecasts at that time.

The results suggest that the merging process is succeeding in improving on the overall performance, over the 0-6h range, of either component forecast taken separately. Adjustment of their relative weights (for example, increasing the weight of the NMM forecast in the second half of the period) might improve some of the scores, but at the expense of making others worse.

Some caution is needed in drawing conclusions about weights from the comparative objective scores of nowcasts and merged forecasts. In both cases evaluation takes place within the region defined by the shallow-layer UDB of the appropriate MRADCM. The region covered by the nowcast moves and sometimes changes shape during the forecast period and does not always completely cover the evaluation region. In the nowcast the uncovered part is left empty (= dry), whereas in the merged forecast, NMM precipitation is used in this area. Although the differences are often small, skill scores for a merged forecast with nowcast and NMM weights set to 1.0 and 0.0 respectively will not necessarily be the same as those for the pure nowcast.

4.1.2 Intensity

Mean RMSF scores at T+1, T+3 and T+6 for the nine cases, weighted according to the numbers of valid samples in the cases, are presented in Table 3.

	RMSF < 2.0 @ T+1	RMSF < 2.5 @ T+3	RMSF < 2.7 @ T+6
Nowcast	2.60	3.38	3.86
NMM	3.37	3.20	3.12
Merged	2.80	3.28	3.17

Table 3. Weighted mean RMSF values for precipitation rate forecasts. Column headers show mandatory (maximum) RMSF values from the Nimrod U-R.

All of the forecast types, nowcast, NMM and merged, have higher (worse) RMSF scores than are demanded by the Nimrod U-R. This is probably because the unavailability of comparable measures of performance of existing precipitation rate forecasts made it difficult to set realistic targets when the U-R was defined.

At T+3 the RMSF values of all three forecast types are similar, with RMSF(merged) intermediate between the other two. At T+1 and T+6, RMSF(merged) approaches the score of the better of the two component forecasts (nowcast at T+1 and NMM at T+6), particularly at T+6. This shows that the merging process is succeeding in its aim of combining the different advantages of the two types of component forecast and producing a better product over the 0-6h forecast range than either could manage separately.

4.2 Accumulation forecasts

Mean RMSF scores at T+1, T+3 and T+6 for the nine cases, weighted according to the numbers of valid samples in the cases, are presented in Table 4.

The average RMSF values presented do not meet the absolute requirement, though they are not wildly adrift, and the T+6 result only exceeds the 2.5 target figure by 0.06.

The results are very good however, considering the quality (RMSF) of the nowcasts and NMM forecasts from which the merged forecasts were formed. The performance of the merged accumulation forecast closely approaches, or exceeds, that of the better of the two component forecasts at all three forecast times, suggesting that the merging process is probably achieving as much as it can, given its input data.

	RMSF < 1.8 @ T+1	RMSF < 2.2 @ T+3	RMSF < 2.5 @ T+6
Nowcast	1.94	2.64	3.26
NMM	3.00	2.73	2.60
Merged	2.01	2.48	2.56

Table 4. Weighted mean RMSF values for accumulation forecasts.
Column headers show mandatory (maximum) RMSF values from the Nimrod U-R.

4.3 Subjective assessments

Subjective examination of the forecasts bore out the results of the objective assessment. The merging program appeared to do the best it could with the data available, suggesting that improvements in the inputs would have more impact than further fine tuning.

In a few instances, adjustments to the weights of the nowcasts and NMM forecasts might have produced improvements at individual forecast times, but no consistent, overall adjustment was indicated.

The main criticisms of the forecasts input to the merging process were (a) the NMM tending to predict too much precipitation, especially in showery situations where precipitation was often not fragmented enough, if at all; and (b) development and decay not being rapid/strong enough in the model. (b) was the more common fault. Prediction of development and decay should be a major benefit of generating merged forecasts, as it is the most important failing of nowcasts used alone.

There is often a noticeable gap at the junction between the merged forecast precipitation and the NMM precipitation which is used alone outside the advected nowcast area. The sharp boundary of the NMM precipitation emphasizes this effect. The improved delineation of the useful radar area in the Nimrod radar analysis (not available in the cases used here) should help to solve this problem.

Some cases had little or no convective activity while others had a lot of showers. It is known that the component forecasts have more difficulty with showers than with widespread frontal rain, and this is reflected in the merged forecasts, though the general distribution of the showers was often quite well forecast, particularly of course at T+1. The NMM forecasts tend to merge showers together into solid areas of rain, and though fractal interpolation of the NMM precipitation (outside the merged product area) helps the appearance of the forecasts, there is still room for improvement.

Further comments on individual forecasts are given in the Appendix.

5 Conclusions

5.1 The merging process is generally successful in combining the relative advantages of nowcasts and NMM forecasts at different stages of the 0-6h Nimrod forecast period.

5.2 The merged forecasts are substantially better than the nowcasts in every average score at T+3 and T+6. The rate and accumulation RMSF scores are slightly worse at T+1 but the location statistics (FAR and HR) are better.

5.3 The objective performance criteria in the Nimrod U-R are met by only a few of the average scores achieved by the merged forecasts, though 'near-misses' also occurred.

5.4 On the whole, the merging process probably did as well as it could, given the forecasts that it had to combine.

5.5 The RMSF criteria set for the merged precipitation rate forecast were probably unrealistic, and result from an absence of comparable performance figures for the component forecasts when the requirement was defined.

5.6 There is no obvious adjustment to the merging process that would produce a *consistent* improvement to the various measured aspects of the merged forecasts.

5.7 The greatest improvement to the quality of the merged forecast will probably result from improvements to its component forecasts. Thus,

> the full Nimrod implementation will use a variational analysis, combining data from several sources with a forecast background field; this is expected to offer a better starting point for forecasts and remove a number of problems associated with the limited area of radar coverage;
>
> further improvements in the NMM will feed through into the merged forecast. Better NMM forecasts will be automatically recognized by program `object_motion` and result in a higher weight being assigned to the NMM forecasts.

5.8 The cases presented here constitute a small sample only, and were mainly selected for the difficulties they would present to an automatic forecasting (or nowcasting) system. As such, they may have exaggerated the improvement over pure nowcasts, while under-estimating the quality of merged forecasts.

5.9 Further work is needed to give realistic shower distributions beyond T+1. Starting the forecast fom the variational analysis should improve this substantially.

6 Recommendations

6.1 It is recommended that the current version of the merged precipitation rate and accumulation scheme be adopted for Nimrod, without further tuning. Although the scheme does not satisfy all the objective criteria in the Nimrod U-R, it appears to be performing

correctly and doing as good a job as can be expected with the current nowcasts and NMM forecasts as input data.

6.2 In view of the small sample of cases used for these tests, and the comment at 5.8 above, it is recommended that a more reliable assessment of the accuracy of the forecasts be made from a one-month trial before implementation, and through routine verification afterwards.

6.3 Performance should be reassessed following introduction of the variational analysis, to determine what further work may be necessary.

6.4 The present merging scheme will take some account of improvements in the component forecasts by making limited adjustments to their relative weights. However, performance should be monitored to see whether more radical adjustment to the weights becomes necessary.

7 References

Conway, B.J., Ryall, G. and Thomas, N. (1993) "Summary report on tests of the automated rainfall extrapolation/advection scheme for Nimrod." *NDG Working Paper No. 64.*

Golding, B.W. (1994) "A Proposed Technique for Merging Extrapolation and Mesoscale Model Forecasts." *NDG Working Paper No. 72.*

Hand, W.H. (1994) "GANDOLF project : CASE STUDY NOTE 24th June 1994." *NDG Working Paper No.* 86.

Thomas, N. (1993) "Adding Orographic Enhancements to the Automated Rainfall Extrapolation/Advection Scheme for NIMROD." *NDG Working Paper No. 69.*

Thomas, N., Conway, B.J. and Golding, B.W. (1993) "Summary Report on the Enhancements and Tests of the Automated Rainfall Extrapolation/Advection Scheme for Nimrod." *NDG Working Paper No. 75.*

Appendix: summary of the nine cases used

21st November 1993, T+0=10z. East coast snow showers.

This case was chosen, as were most of the others, to exemplify particular difficulties. Although an easterly wind was bringing snow showers onto the east coast of Great Britain for most of the day, the showers did not cross the Pennines and Grampians and so advection would have been an inappropriate forecast method. The forecasts needed to show the showers decaying and this was only possible in the model, hence this was seen as a good test for producing forecasts with radar-resolution detail but model development and decay. Another feature of this case was the generation of showers in the Bristol Channel by land breeze convergence from South Wales and the South West Peninsula. These showers also slowly died out during the forecast period.

The overall impression of the merged forecasts was good but the model's over-prediction of precipitation in the North Sea was evident. This enabled the real precipitation area to be forecast by the model but at the expense of producing a lot of false alarms ("blanket coverage"). The advection forecast moved the showers to the west coast as expected but the size of the shower area was better.

25th November 1993, T+0=12z. Decaying front.

A cold front which was initially quite active, crossed the country from north west to south east and decayed, eventually into only a few fragments over Wales and the north midlands. At the same time the front also decreased in speed and ultimately stopped. This case therefore provided a test which involved decay and a change in speed from that which advection might use if linear extrapolation was chosen.

The merged forecasts gave a good indication of the frontal movement and of the decay in precipitation rates but unfortunately the rates did not decay to zero, i.e. the front did not fragment as it should have done although it did become weaker. This was because the model's decay of the front was not strong enough. As a result the FAR was exceptionally high at T+3 and T+6 (the highest at these times for all the cases).The position and width of the front were both accurately predicted by both the model and the advection forecasts (which used model wind advection), with the exception of the T+3 forecast which predicted precipitation over the Grampians and Cairngorms (this actually appeared to jump to the lee of the mountains). This gave an exceptionally low HR at T+3 although, as at all the other forecast times, this was still better than the HR for the advection forecast. The weights for each input forecast crossed over (became equal) between T+2 and T+3 and for this case it may have been advantageous if this had happened one hour later, i.e. if the T+3 forecast had had more advection input and less model input. Unfortunately the model forecasts also brought a semi-continuous area of often heavy precipitation into the north west of Scotland behind the front instead of a more broken area of lighter showers. This also helped to increase the FAR later in the forecast period.

7th December 1993, T+0=04z. Front clearing with showers behind.

The front on this day also had a wave in it, complicating the movement of the precipitation. As the front moved south east out of the British Isles numerous showers followed from the North West to affect most of the country by the end of the forecast period, especially in the north and west.

One of the better cases in terms of FAR and HR, this case actually exceeded the user requirement and did appear to "get the best of both worlds" from the model and advection

input forecasts. The model's predictions of the front were too wide and ahead of its real position but these were checked by the advection forecasts. The showers were also in advance of their real positions but could not be checked by the advection forecasts because they were not present in them : the advection forecasts only contain the precipitation detectable at T+0 and cannot "bring in" data from beyond the limits of the radar network (the "no data" area). If the area of precipitation in the model forecasts which represented the showers had been more broken then the merged forecasts might have been even better, however this is a problem with the model input, as is the area being too far ahead, and not with the merging routine and so cannot be overcome by simply altering the relative weights of the input forecasts. This case would not benefit from altering the weights to give either component greater emphasis.

11th February 1994, T+0=04z. Front "changing direction".

Although on this day the front involved did not actually change direction (it merely halted in its progression eastwards) the decay of precipitation from the north along the front gave the appearance of a front first of all moving west to east and then sliding from north to south. The test was to see if this change could be predicted as the advection forecast was slowly blended into the model forecast.

While the model forecasts did indicate a decrease of precipitation rates giving the impression of southward motion along the front, the decay was not to zero and so, as the advection forecasts cannot simulate decay, the merged forecasts tended to have a little too much precipitation in them towards the end of the period, when the model had a greater influence. Consequently merging the advection forecasts with the model forecasts had a detrimental effect in predicting the precipitation area, which may have best been overcome not just by altering the weights to give the advection forecast greater emphasis for longer, but by not merging the two at all. It is recognised however that the decrease in precipitation rates may have helped to provide more accurate accumulation predictions than the advection forecasts alone would have done. The merged forecasts were only slightly worse than the advection forecasts in terms of FAR (because of the influence of the model), but in terms of HR they could not match the model which gained the highest scores by using blanket coverage of the precipitation area (at the expense of poor FAR). However, this was seen as another good case in that it achieved the user requirement in five out of the six targets, the only failure being the T+6 FAR which was narrowly missed by 2.12%.

24th February 1994, T+0=04z. Frontal decay and showers.

The "messy" decay of the front into a number of ragged and disorganised areas of precipitation on this day was seen as a difficult case for an automatic system to handle. This turned out to be true even for the merged forecasting system. The FARs and HRs were among the worst for any case. However, the FARs, except at T+3, were still better than for either of the input forecasts. The advection forecasts failed to predict the decay of the objects contained within them, as is already known and accepted, and so, after starting out well, they progressively forecast too much precipitation although what precipitation from the front over southern Scotland did remain was forecast also. The showers in the South West were very soon over-forecast. The model forecasts contained the hint of decaying precipitation but gave the impression of "knowing there's something out there but not quite what it is or where it is". Precipitation down the Pennines and off the North coast were both false but the real precipitation over southern Scotland was completely missed by the model. Also, the showers in the South were forecast as two solid bands by the model. Given such inputs the merging

program had little chance of producing good forecasts. This was the only case where the model precipitation forecast at T+0 was so bad that it would have resulted in a negative weighting. However, such a circumstance is not allowed and all weights below 0.001 are held at 0.001.

The merged forecasts were useful in providing an overall impression of the situation but were not accurate enough in their detail. The showers in the South West tended to become more clumped rather than move away and/or decay.

27th February 1994, T+0=14z. Rotation and decay.

Chosen for its good display of frontal rotation followed by decay, this case had a small depression tracking eastwards across Northern Ireland into northern England / southern Scotland where it became slow moving and started to decay. The advection forecasts were reasonable and had a good FAR but at the expense of HR, i.e. some precipitation was missed. Precipitation over Ireland should have been over the Irish Sea and more precipitation was also required further north over Scotland than predicted: the system could perhaps have been rotated a little faster with some opening out of the spiral arms. A shower initially over the Cherbourg Peninsula was advected correctly but was unable to decay in the nowcasting scheme. In the merged forecasts this shower did decay but not by as much as it should have done because of the over prediction of precipitation on the near continent by the model which still allowed light precipitation in this area.

The model forecasts over-predicted the amount of precipitation (to the detriment of the FAR), but at least most of the real precipitation was forecast this way. As a result the merged forecasts contained more precipitation than the advection forecasts but not quite as much as the model forecasts. This gave rise to slight over-predictions, shown by the FARs, but good HRs. The Critical Success Index (CSI = A/(A+B+C) in the notation of §3.2.1) showed the merged forecasts to be better than either component.

Apart from predicting the precipitation areas quite well, the other main characteristic of the merged forecasts was over-estimating the populations of pixels in each precipitation rate. This gave more intense precipitation forecasts, especially after orographic enhancement, with a bullseye effect in the rates around Edinburgh which was present but much smaller than predicted. Altering the weights would not have helped in this case.

9th April 1994, T+0=08z. Showers, fronts and vortices.

On 9th April, 1994 a small but well-defined vortex moved quickly eastwards across southern England during the early morning. An arctic front swung down over the whole country during the day as it moved around a depression in the North Sea. Gradually the precipitation turned more wintery throughout the day, with snow falling in Sussex and Kent in the evening. Showers were associated with both phenomena.

Merging the advection and mesoscale model forecasts produced good results but with one or two exceptions. Both the model and the advection technique forecast the arctic front quite well. The model over-predicted the extent of the precipitation and the advection technique under-predicted it and so the net result was quite good. It might have been improved by giving the advection input more weight and the model input less weight as there was some over-prediction in this area, although most of this was caused by the model bringing in a continuous sheet of showers to the Western Isles (in the advection forecasts' no data area) rather than a speckling of showers. The only fault with the arctic front itself is that the extra width of the front in the model led to a false extension which curled back over Grampian in the merged product.

The bands of showers in the South were severely under-predicted by the advection technique and were better in the model. Unfortunately, however, they were too far south (as they were in the advection forecasts) and so giving either input more weight relative to the other would not have helped in this situation. Indeed it could be argued that in the South the model should have had more weight in order to better predict the showers moving away over France, in contrast to any requirement further north. As the weights of the inputs affect the whole frame it is probably better to leave them as they are. The CSIs calculated for this case indicated that the merged forecasts were actually better than their components except from T+5 when there was a very small slip.

19th April 1994, T+0=07z. Rotating fronts, showers and a wave.

A depression was located over northern Scotland with a cold occlusion wrapped around it from the Western Isles, around Scotland into the North Sea and across northern England into Ireland, where it was analysed as a cold front. The precipitation along this front was quite broken and a further trough of showers lay just ahead of it. During the day, particularly the afternoon, a small wave ran along the front.

The merged forecasts for this case were good although the coarser resolution of the model input produced a large patch of rain in Scotland rather than a heavy speckling of showers at the end of the forecast period. The showers in the trough, which could not decay in the advection forecasts, did decay in the merged forecasts. Giving the model a little more weight at the end of the forecast period might have improved the forecasts slightly at T+5 and T+6 but it would only take a little too much model input to increase the FAR (although this would increase the HR as well). It would also result in a "solidifying" of showers and so give the wrong impression.

24th June 1994, T+0=13z. Mesoscale Convective System (M.C.S.).

A band of thundery frontal rain lay down the western side of the British mainland with an arc of such precipitation extending around the north and west coasts of Ireland, at the initial (base) time. A heavy shower then developed over the north French coast and moved across the Channel Islands, Cherbourg Peninsula, English Channel and south east England, developing further into an M.C.S. The test in this case was to see if this development, which could not be simulated by the advection forecasts, could be put into the forecasts by merging with the mesoscale model.

The overall impression given by the merged forecasts was good in that the forecast precipitation was in the correct place and there was the hint of some development in the English Channel. However, the development in the model was not strong enough and so the merged forecasts failed to show the M.C.S. and its extreme precipitation rates, instead showing a rather extended and heavy shower. (It should be pointed out though that the precipitation rates given by the Chenies radar were up to twice what they should have been at the limit of its range (Hand, 1994).) It was unfortunate that both inputs agreed to place their forecast precipitation in the gaps of the fragmented precipitation over Scotland and this resulted in almost an anti-correlation at T+6, but this cannot be improved by the merging process. The merged forecasts appeared to make the best of the inputs available. Altering the weights of the inputs would not help in this case.

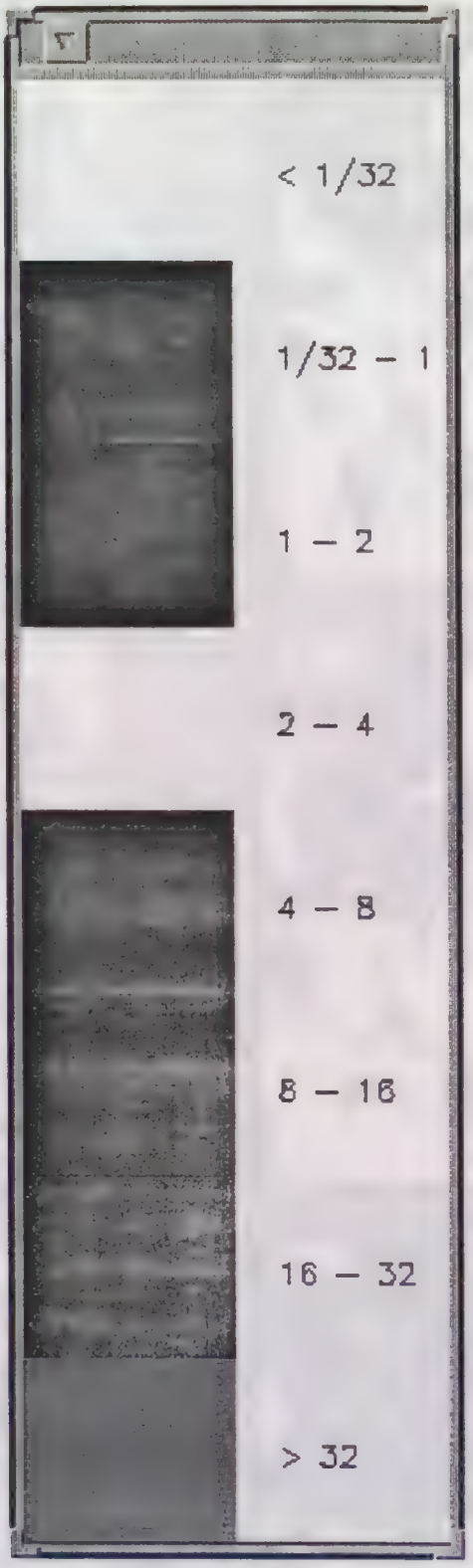
Figures

The first Figure provides a colour key for all the precipitation forecasts and actuals (rates and accumulations).

The remaining Figures show forecasts and actuals for all the cases used.

Figures headed "*date* merged f/c *time*" show the merged precipitation rate forecasts for all the cases at T+1, T+3 and T+6, alongside the FRONTIERS quality-controlled radar actuals ("MRADCMs") at those times.

Figures headed "*date* merged acc f/c *time*" show the corresponding merged 60-minute accumulation forecasts, alongside actuals formed from the sums of MRADCMs, as described in §3.3.



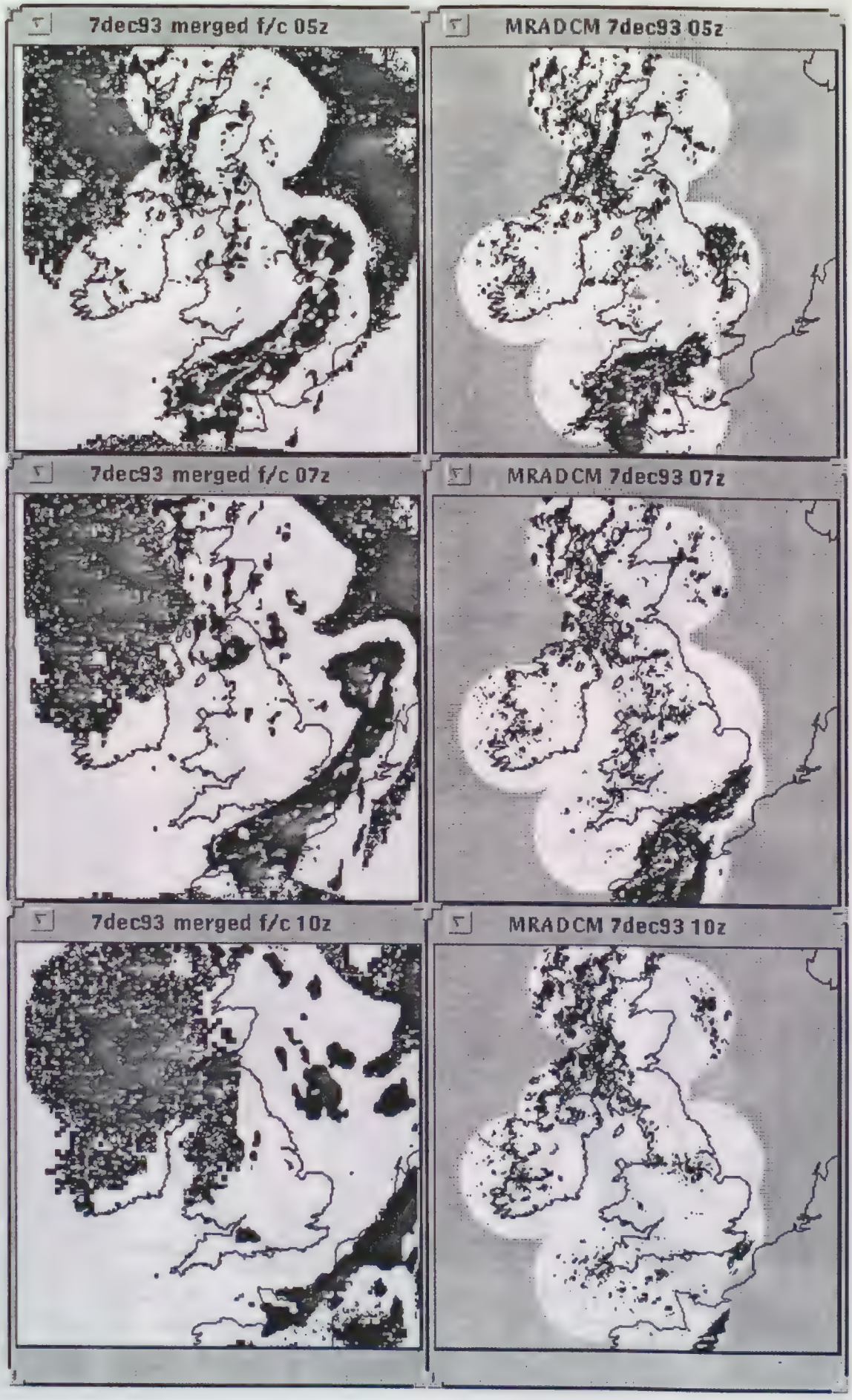
Colour key for images – precipitation rates are in mm/hr, accumulations are in mm

21 nov93 merged f/c 11z
MRADCM 21 nov93 11z
21 nov93 merged f/c 13z
MRADCM 21 nov93 13z
21 nov93 merged f/c 16z
MRADCM 21 nov93 16z

21nov93 merged acc. f/c 11z
summed MRADCM 21nov93 11z
21nov93 merged acc. f/c 13z
summed MRADCM 21nov93 13z
21nov93 merged acc. f/c 16z
summed MRADCM 21nov93 16z

25nov93 merged f/c 13z
MRADCM 25nov93 13z
25nov93 merged f/c 15z
MRADCM 25nov93 15z
25nov93 merged f/c 18z
MRADCM 25nov93 18z

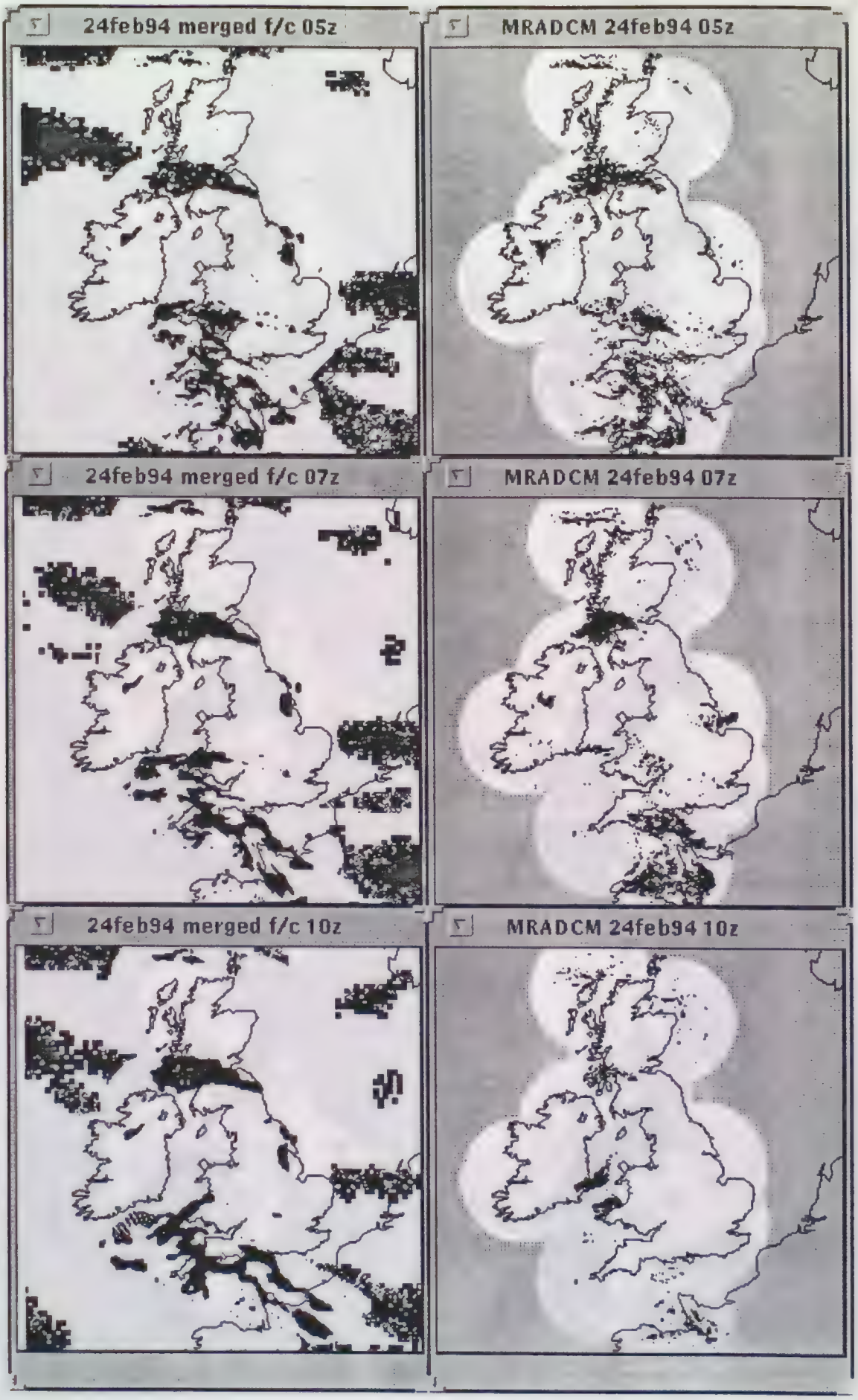
25nov93 merged acc. f/c 13z
summed MRADCM 25nov93 13z
25nov93 merged acc. f/c 15z
summed MRADCM 25nov93 15z
25nov93 merged acc. f/c 18z
summed MRADCM 25nov93 18z


7dec93 merged f/c 05z
MRADCM 7dec93 05z
7dec93 merged f/c 07z
MRADCM 7dec93 07z
7dec93 merged f/c 10z
MRADCM 7dec93 10z

7dec93 merged acc. f/c 05z
summed MRADCM 7dec93 05z
7dec93 merged acc. f/c 07z
summed MRADCM 7dec93 07z
7dec93 merged acc. f/c 10z
summed MRADCM 7dec93 10z

11feb94 merged f/c 05z
MRADCM 11feb94 05z
11feb94 merged f/c 07z
MRADCM 11feb94 07z
11feb94 merged f/c 10z
MRADCM 11feb94 10z

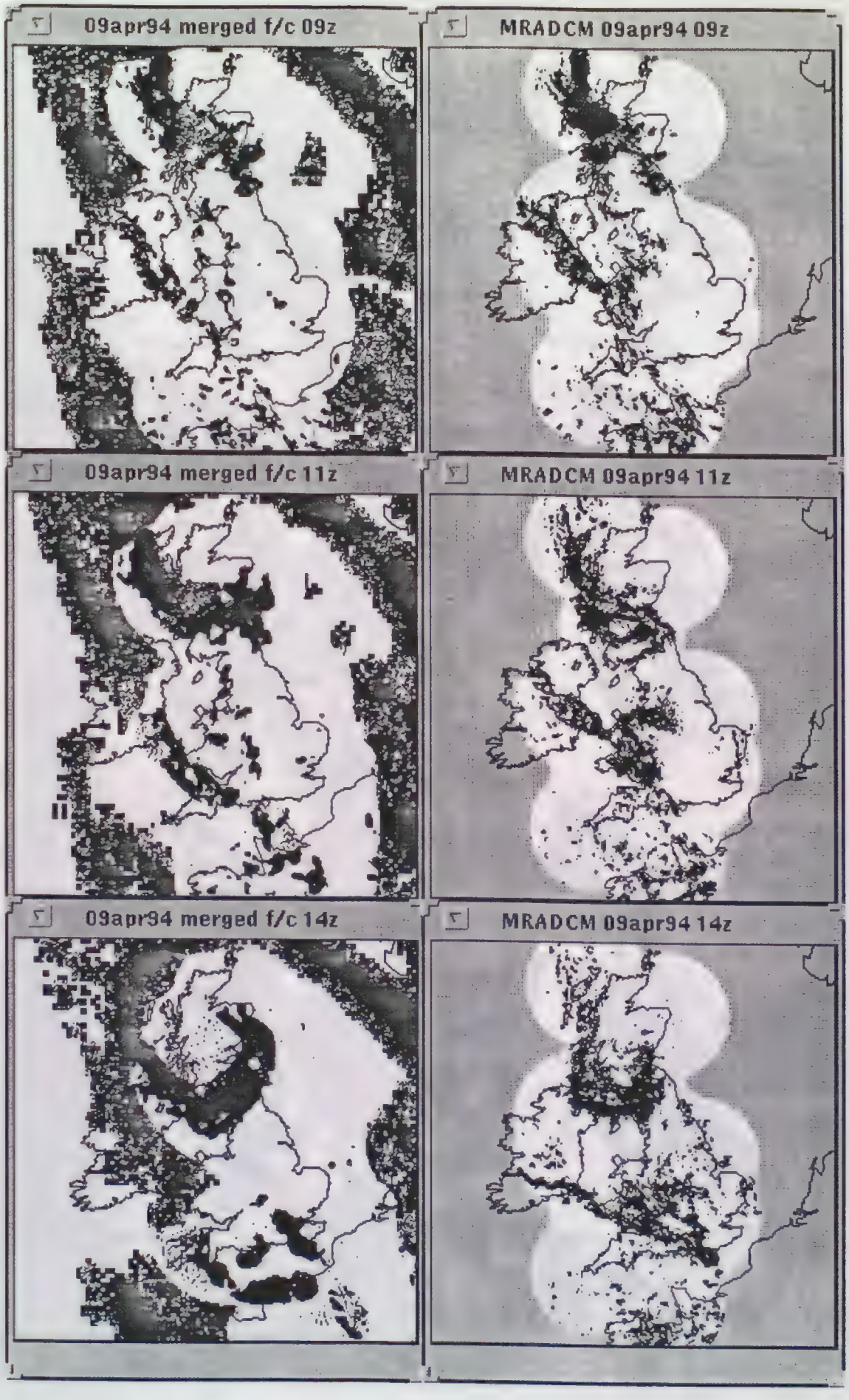
11feb94 merged acc. f/c 05z
summed MRADCM 11feb94 05z
11feb94 merged f/c 07z
summed MRADCM 11feb94 07z
11feb94 merged f/c 10z
summed MRADCM 11feb94 10z

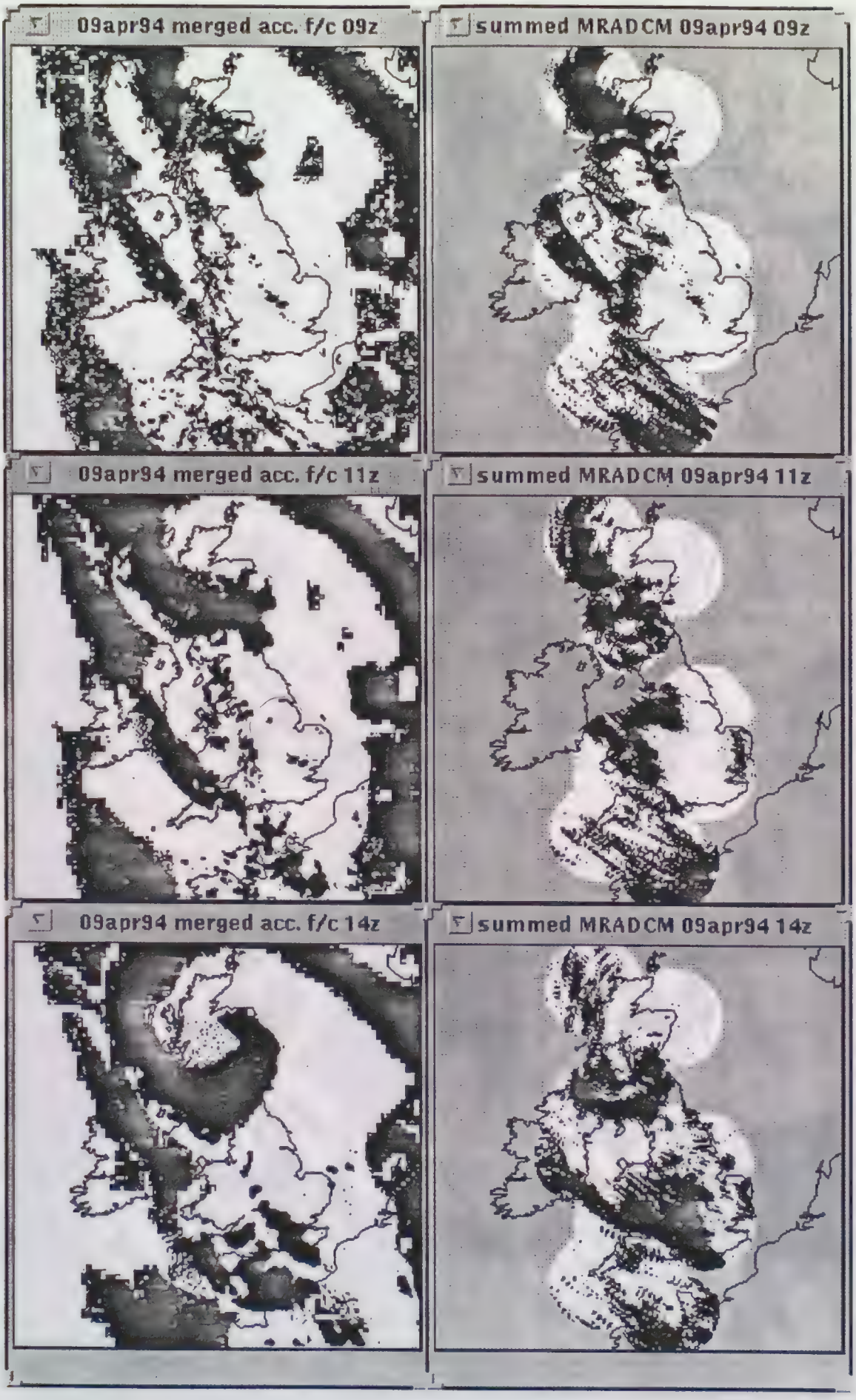

24feb94 merged f/c 05z
MRADCM 24feb94 05z
24feb94 merged f/c 07z
MRADCM 24feb94 07z
24feb94 merged f/c 10z
MRADCM 24feb94 10z

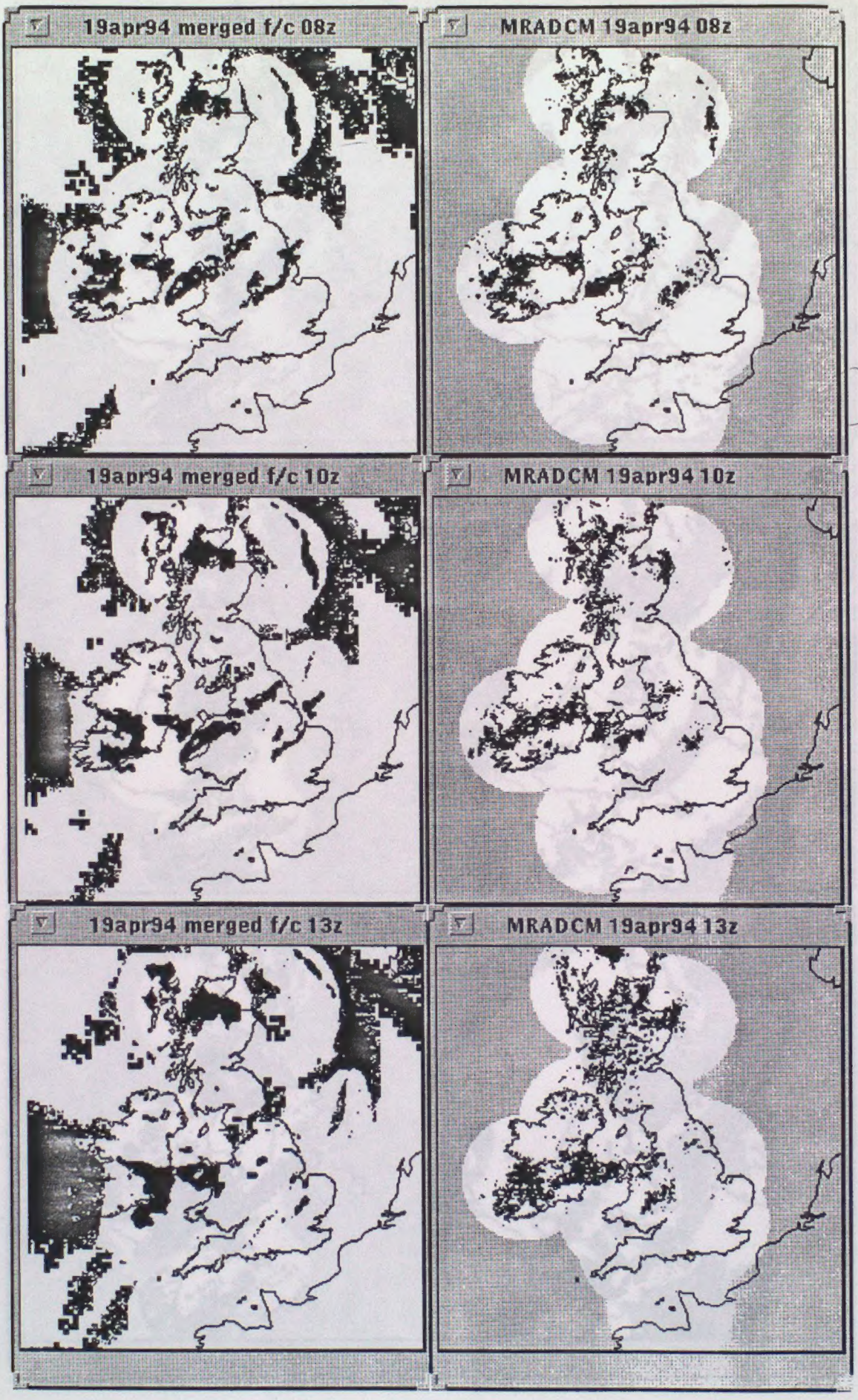
24feb94 merged acc. f/c 05z
summed MRADCM 24feb94 05z
24feb94 merged acc. f/c 07z
summed MRADCM 24feb94 07z
24feb94 merged acc. f/c 10z
summed MRADCM 24feb94 10z

27feb94 merged f/c 15z
MRADCM 27feb94 15z
27feb94 merged f/c 17z
MRADCM 27feb94 17z
27feb94 merged f/c 20z
MRADCM 27feb94 20z

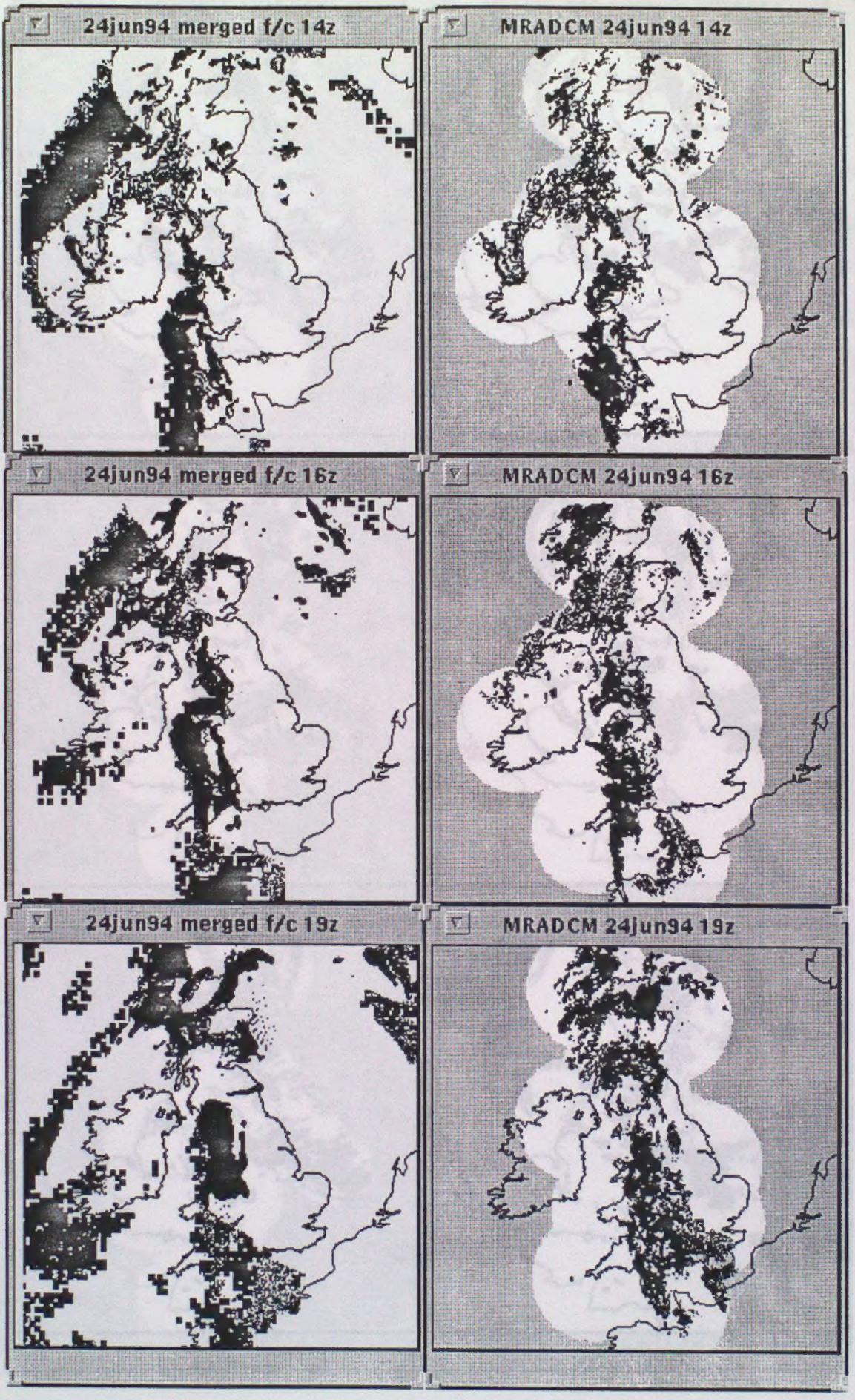
27feb94 merged acc. f/c 15z
summed MRADCM 27feb94 15z
27feb94 merged acc. f/c 17z
summed MRADCM 27feb94 17z
27feb94 merged acc. f/c 20z
summed MRADCM 27feb94 20z

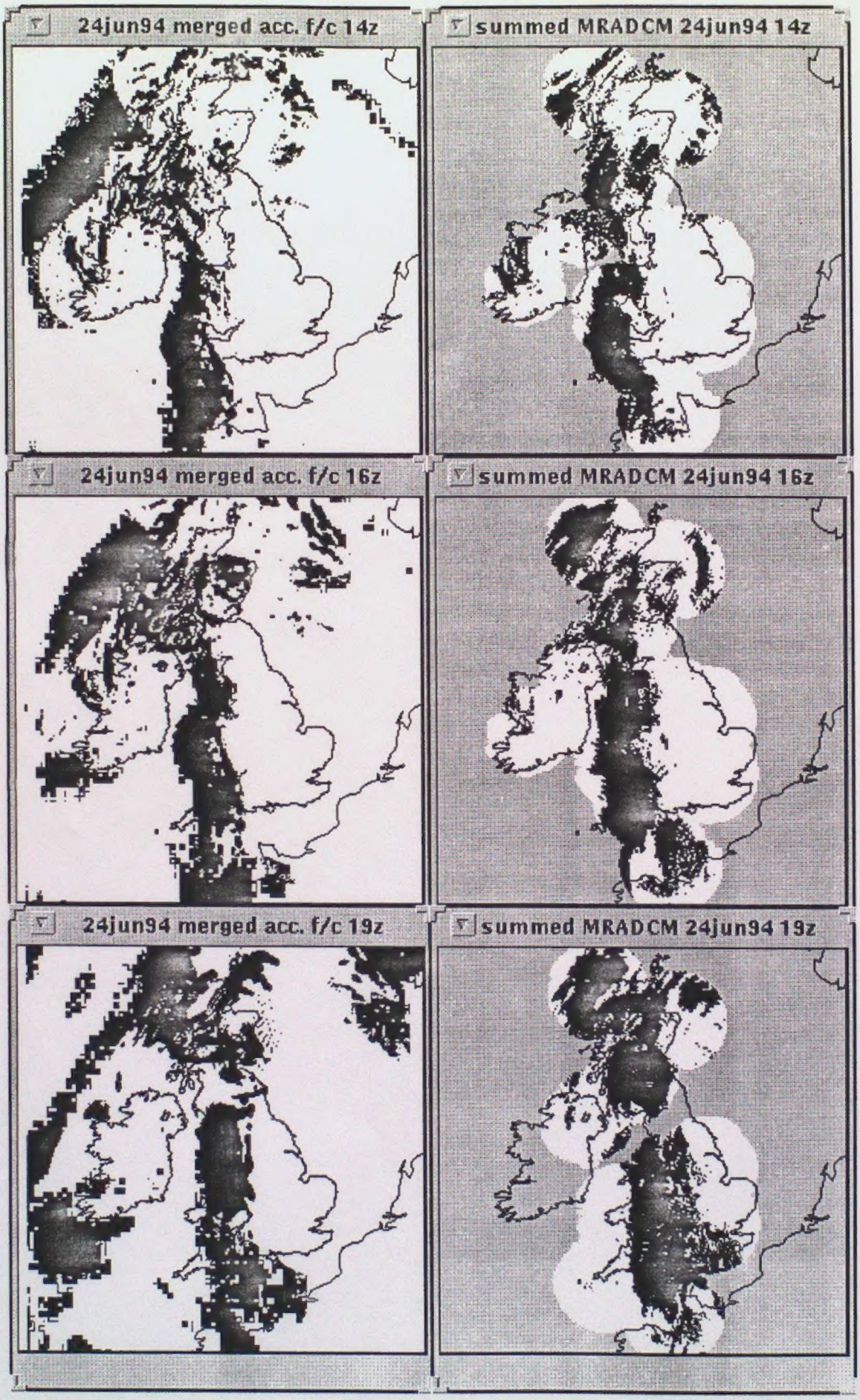

09apr94 merged f/c 09z
MRADCM 09apr94 09z
09apr94 merged f/c 11z
MRADCM 09apr94 11z
09apr94 merged f/c 14z
MRADCM 09apr94 14z


09apr94 merged acc. f/c 09z
summed MRADCM 09apr94 09z
09apr94 merged acc. f/c 11z
summed MRADCM 09apr94 11z
09apr94 merged acc. f/c 14z
summed MRADCM 09apr94 14z


19apr94 merged f/c 08z
MRADCM 19apr94 08z
19apr94 merged f/c 10z
MRADCM 19apr94 10z
19apr94 merged f/c 13z
MRADCM 19apr94 13z

19apr94 merged acc. f/c 08z
summed MRADCM 19apr94 08z
19apr94 merged acc. f/c 10z
summed MRADCM 19apr94 10z
19apr94 merged acc. f/c 13z
summed MRADCM 19apr94 13z


24jun94 merged f/c 14z
MRADCM 24jun94 14z
24jun94 merged f/c 16z
MRADCM 24jun94 16z
24jun94 merged f/c 19z
MRADCM 24jun94 19z


24jun94 merged acc. f/c 14z
summed MRADCM 24jun94 14z
24jun94 merged acc. f/c 16z
summed MRADCM 24jun94 16z
24jun94 merged acc. f/c 19z
summed MRADCM 24jun94 19z